Article:

Margaritis, E. orcid.org/0000-0002-7307-8437 and Kang, J. (2016) Relationship between green space-related morphology and noise pollution. Ecological Indicators, 72. pp. 921-933. ISSN 1470-160X

https://doi.org/10.1016/j.ecolind.2016.09.032

Relationship between green space-related morphology and noise pollution

Efstathios Margaritis[a], Jian Kang[a*]
[a]*School of Architecture, University of Sheffield, Western Bank, Sheffield S10 2TN, United Kingdom*

** Corresponding author

Abstract

Green spaces have been proved to have a positive effect on traffic noise pollution in the local scale; however their effects have not been explored on the urban level. This paper investigates the effects of green space-related parameters from a land cover viewpoint on traffic noise pollution in order to understand to what extent greener cities can also be quieter. A triple level analysis was conducted in the agglomeration, urban and kernel level including various case study cities across Europe. The green space parameters were calculated based on land cover data available in a European scale, while traffic noise data were extracted from online noise maps and configured in noise indices. In the first level 25 agglomerations were investigated, six of which were further analyzed in the urban and kernel levels. It was found that the effect of green spaces on traffic noise pollution varies according to the scale of analysis. In the agglomeration level, there was no significant difference in the cluster of the higher green space index and the percentage of people exposed in the lowest (55-59 dB(A)) or the highest noise band of more than 70 dB(A). In the urban level it was found that lower noise levels can possibly be achieved in cities with a higher extent of porosity and green space coverage. Finally, in the kernel level a Geographically Weighted Regression (GWR) analysis was conducted for the identification of correlations between noise and green. Strong correlations were identified between 60% and 79%, while a further cluster analysis combined with land cover data revealed that lower noise levels were detected in the cluster with higher green space coverage. At last, all cities were ranked according to the calculated noise index.

Keywords: Noise pollution, Green spaces, Urban morphology, GIS, Cluster analysis

2017 Ecological Indicators
Date Received: 20 May 2016 **Date Accepted**: 19 September 2016
Available online: 6 October 2016

1. Introduction

The problem of exposure to traffic noise is rapidly increasing and is closely related with the rapid urbanization process taking place around the world. Nowadays, 54 per cent of the world's population lives in urban areas, a proportion that is expected to rise to 66 per cent by the year 2050 (United Nations, 2012). As a consequence of this process, noise annoyance problems are caused, leading one out of five Europeans to be regularly exposed to sound levels during the night that can trigger serious damage to health (WHO, 2009). This is the reason why the European Community adopted measures for the noise reduction through the Environmental Noise Directive (2002/49/EC), hereinafter called the "END".

Other benchmarking reports on a European scale classified cities according to various urban forms (Schwarz, 2010) or sustainability indices (The Economist, 2009). However, the last report refers to transport variables, which cannot provide a direct assessment of the noise pollution in these cities. From the viewpoint of soundscape, studies on a European context are rare and there is the need to establish a common protocol for soundscape exposure assessment (Lercher and Schulte-Fortkamp, 2015). Lastly, in the European Green Capital Award (European Comission, 2014), the quality of the acoustic environment was taken into consideration using the exposure of people above or below certain noise bands whenever these results were available.

On the other hand, green spaces comprise one of the inherent elements of urban form apart from outdoor spaces, road and building infrastructure (Valente-Pereira, 2014). All these factors can affect traffic noise distribution in various levels. Previous studies have examined their effect either on the building level (Oliveira and Silva, 2010; Salomons and Berghauser Pont, 2012; Silva et al., 2014) or in large neighbourhoods (Hao et al., 2015a; Tang and Wang, 2007). At the city level, traffic noise has been measured either through the use of landscape metrics (Oliveira and Silva, 2010; Mõisja et al., 2016; Weber et al., 2014) or with the help of indicators related to road and building characteristics (Aguilera et al., 2015; Hao et al., 2015b). Finally, on regional level, an attempt to approach noise issues by emphasizing on the identification and designation of "quiet areas" according to land use criteria was performed by Votsi et al., 2012.

The relationship between traffic noise and green spaces has been investigated in multiple scales. The majority of these studies focuses on the small-scale, where the absorption or scattering effects of branches and leaves are investigated (Attenborough, 2002; Aylor, 1972; HOSANNA, 2014; Huddart, 1990; Van Renterghem et al., 2014). This kind of researches cover a wide range from a single tree (Yang et al., 2011) to different plant types (Horoshenkov et al., 2013) or various tree belts (Van Renterghem et al., 2012). Interesting quantitative approaches on the park scale have also been developed by Pheasant et al. (2010) with the Tranquillity Rating Prediction (TRAP) tool and by Brambilla and Gallo (2016) with the QUIETE index. At the city scale, previous works have selectively emphasized the quantitative assessment of parks concerning traffic noise reduction (Cohen et al., 2014; González-Oreja et al., 2010). Other studies investigating also the users' perception of the acoustic quality in the parks have been performed by Brambilla et al., 2013; Brambilla & Maffei, 2006; Weber, 2012.

However, there is little evidence on the effect of green spaces as a land use parameter on traffic noise. The most frequent use is through land use regression (LUR) models (Goudreau et al., 2014; Ragettli et al., 2016), or in a local scale through the TRAP tool by Pheasant et al. (2010), which can be very useful in the absence of noise maps, but still of limited range and dependent on on-site noise measurements.

Widely used indicators for green spaces usually refer to green space coverage (Fuller and Gaston, 2009; Zhao et al., 2013) or green space per inhabitant (ISO 37120; WHO, 2010). Others include also the proximity to green areas (Herzele and Wiedemann, 2003; Hillsdon et al., 2006; Kabisch et al., 2016; Morar et al., 2014; Natural England, 2010; Ståhle, 2010) or more complex indices referring to the balance between green and built up areas (De la Barrera et al., 2016). Furthermore, there are shape-oriented indices, which can also measure the distribution of green spaces (Margaritis and Kang, 2016; McGarical and Marks, 1994; Verani et al., 2015).

Consequently, the aim of this research is to provide, through the analysis of noise mapping and land cover data, an evidence of whether greener cities can also be quieter. This research question was investigated on three geographical levels (agglomeration, urban, kernel) using a top-down perspective in order to investigate also the effect of the scale on the results. The correspondent targets were: 1) the effect of forest, urban green and agricultural areas on noise distribution in the agglomeration level, 2) the effect of green space indicators on noise indices in the urban level and 3) the effect of green space indicators on noise indices in the kernel level of the investigated cities.

2. Methods

The methodology used investigates the relationship between green space and noise indicators in three different levels starting from a general to a more focused scale. For comparison purposes, the six cities namely: Antwerp, Helsinki, Brussels, Prague, Amsterdam and Rotterdam mentioned in levels two and three also exist in level one. The first part refers to the agglomeration level as defined in the END, while the second one refers to the urban level, which is equal to or smaller than the administrative borders of the cities. Finally, the third level refers to small kernel areas of 500x500 m each, covering the six cities. It should also be made clear that the level of accuracy in these noise maps is acceptable for this kind of strategic analysis, in spite of the differences in the production software or input data, since all the results have to comply with the END requirements.

2.1 Agglomeration level

2.1.1 Case studies selection

Out of the available 216 agglomerations in the European Environment Information and Observation Network database (EIONET, 2015), 25 were selected (12%) covering 11 out of 20 European countries. This was the maximum available sample size, since the selection process was based on the availability of both noise mapping and land cover data for the same agglomerations. The aim was to mostly cover medium-sized cities between 100,000 and 500,000 inhabitants, with bigger ones to serve as a means of comparison. The population density of the sample as shown in Fig.1 has a broad range between 842 and 6,249 people / km^2, while the population size of the agglomerations varies between 117,073 and 1,543,781 inhabitants. The agglomeration area ranges between 110 and 496 km^2 as presented in Table 1, while the green area coverage ranges between 35 and 405 km^2. Finally, the agglomeration borders were provided by the EIONET Agency as generalised polygon shapefiles.

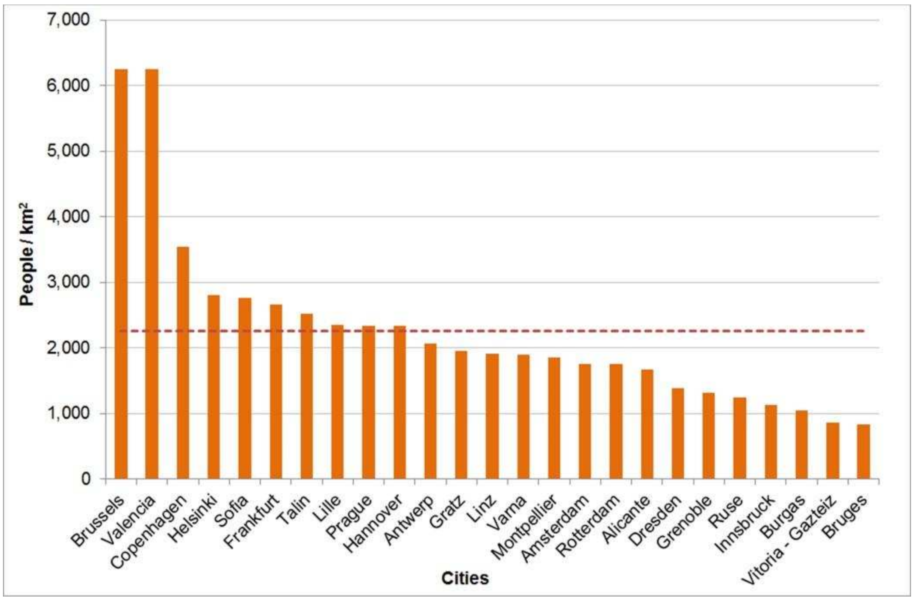

Fig. 1. Population density and average value (dotted line) in the agglomeration level. *Source: EIONET*

Table 1
General characteristics of the 25 agglomerations sorted in a descending form for the population density field.

City	Area (km^2)	Pop. Density ($people/km^2$)	Total Green (km^2)	Total Green (m^2/person)
Brussels	160	6,249	38	38
Valencia	130	6,249	94	115
Copenhagen	302	3,546	104	97
Helsinki	200	2,805	69	123
Sofia	492	2,760	116	85
Frankfurt	250	2,660	107	160
Tallinn	159	2,527	100	250
Lille	426	2,348	196	196
Prague	496	2,340	282	243
Hannover	238	2,333	96	174
Antwerp	205	2,062	35	83
Gratz	128	1,960	56	223
Linz	111	1,911	48	225
Varna	169	1,892	95	297
Montpellier	155	1,855	70	242
Amsterdam	152	1,752	46	173
Rotterdam	150	1,752	38	146
Alicante	200	1,674	136	406
Dresden	329	1,387	187	410
Grenoble	327	1,315	405	942
Ruse	127	1,240	80	508
Innsbruck	110	1,133	84	672
Burgas	219	1,050	204	884
Vitoria - Gazteiz	276	857	230	972
Bruges	139	842	71	602

2.1.2 Noise data and indicators

As Europe moves forward towards a common noise policy with harmonised noise indicators; population exposure assessments can become a valuable tool of evaluating the current and future noise conditions. The current data were sent to EIONET from the member states through reports submitted in 2007 and updated until August 2013. Population exposure is measured by the percentage of people affected per noise band using the L_{den} index as mentioned in Table 2. This index was used in the current study in the absence of original noise mapping data at the agglomeration level.

Table 2
Definition of variables related to noise (*Source: EIONET*) and green spaces (*Source: Urban Atlas*) in the agglomeration level.

Variables		
Noise indices *(% of people affected per noise band)*	***Green space indices***	
L_{den}(55-59)		
L_{den}(60-64)	Agricultural areas (%)	Agricultural areas (m^2/person)
L_{den}(65-69)	Forest areas (%)	Forest areas (m^2/person)
L_{den}(>70)	Urban green areas (%)	Urban green areas (m^2/person)

2.1.3 Green space data and indicators

Green spaces at this level are divided in three categories, namely: a) Agricultural areas, b) Forest areas, and c) Urban green areas. These categories have already been defined in the Urban Atlas land use dataset (European Environment Agency, 2010), where green space data was downloaded from. Accordingly, the correspondent indices are expressed as the coverage ratio per category and as the percentage per person (Table 2). From the noise perspective, these areas represent the porous surfaces with higher sound absorption than rigid surfaces.

The Urban Atlas land cover dataset is available for Large Urban Zones with more than 100,000 residents. The final data are provided in a scale of 1:10,000, while the original data come from satellite images of 2.5m resolution, which is very precise for the analysis on a city scale. However, it can also be used complementarily to other datasets such as CORINE land cover, which makes the analysis easier and more comprehensive.

2.2 Urban level

2.2.1 Case studies

From the 25 agglomerations, six cities were selected as presented in Fig.2 in order to perform a more detailed analysis on the urban level. The noise mapping area in these cases is equal to or smaller than the agglomeration area, firstly because the main emphasis is in the core city parts and secondly because agglomerations are abide by specific population criteria (2002/49/EC).

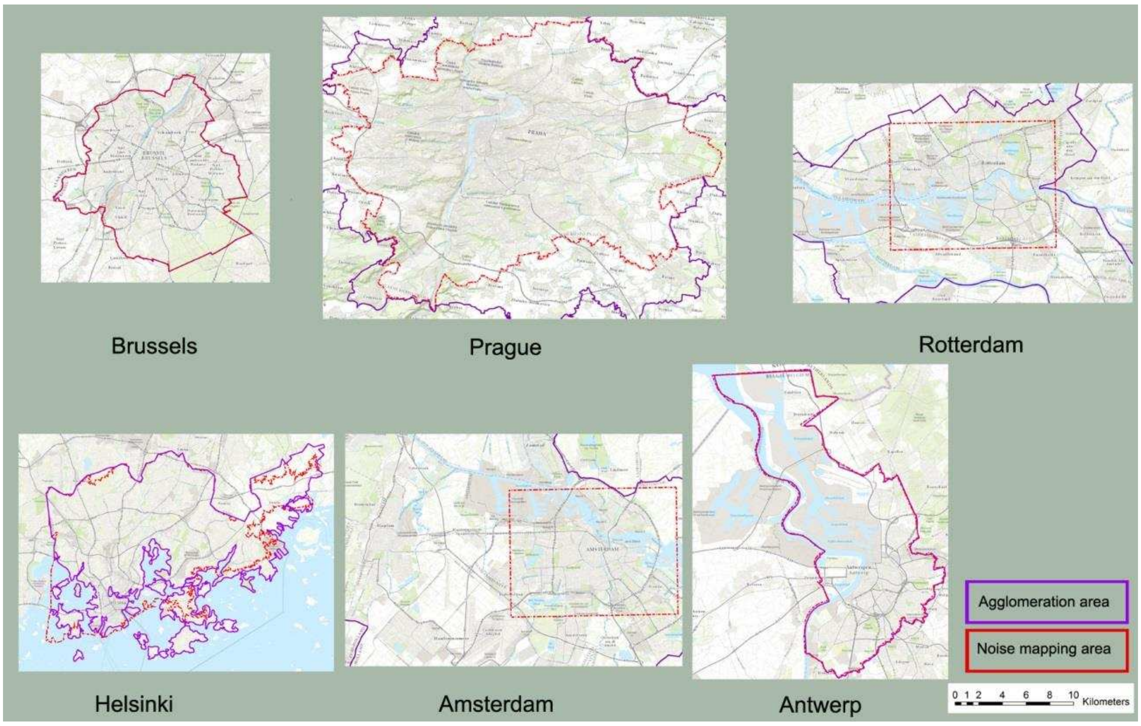

Fig. 2. Degree of differentiation between the agglomeration and the noise mapping areas in the six cities. *Source: Brussels Institute for Environmental management, Czech Republic: Ministry of Health, Netherlands: Calculation of road traffic noise, Helsinki City Council, Antwerp City Council, Topographic Basemap: ESRI)*

There were two criteria for the selection process: a) the city should have an available online noise map, b) the noise map should be continuous and cover the entire region, not only the major roads. According to Table 3, the population size of the selected cities ranges between 464,009 and 1,160,641 inhabitants. Apart from Prague and Brussels the rest of the cities are in the upper population limit of mid-sized cities ($M_{population}$=520,651) based on the classification criteria by Bolton and Hildreth (2013). Additionally, population density in five out of six cases range between 2,340 and 3,715 people ($M_{denisty}$=3,425) per km^2 (Table 3).

Table 3
General characteristics of the cities in terms of size and population density.

Agglomeration Name	Agglomeration area (km^2)	Noise mapping area (km^2)	Population (noise mapping area)	Density (people/km^2)
Brussels	160	162	999,899	6,172
Amsterdam	219	152	564,664	3,715
Rotterdam	326	149	464,009	3,114
Helsinki	186	200	570,578	2,853
Antwerp	205	205	483,353	2,358
Prague	496	496	1,160,641	2,340

2.2.2 Noise data and indicators

In every noise map it was necessary to calculate the percentage of pixels belonging to the different noise bands. For similarity purposes and in order to have comparable results among all the cities five noise bands were defined as presented in Fig.3.

All maps were imported in ArcGIS and converted to a raster file of 10-meter grid resolution through a supervised classification. The same grid size has been used for the noise maps produced by the Department of Environment, Food and Rural Affairs (DEFRA, 2007). An identical process was followed for the green space data. Then with the help of "Zonal Statistics" tool it was rendered feasible to have the exact number of noise and green space pixels per band.

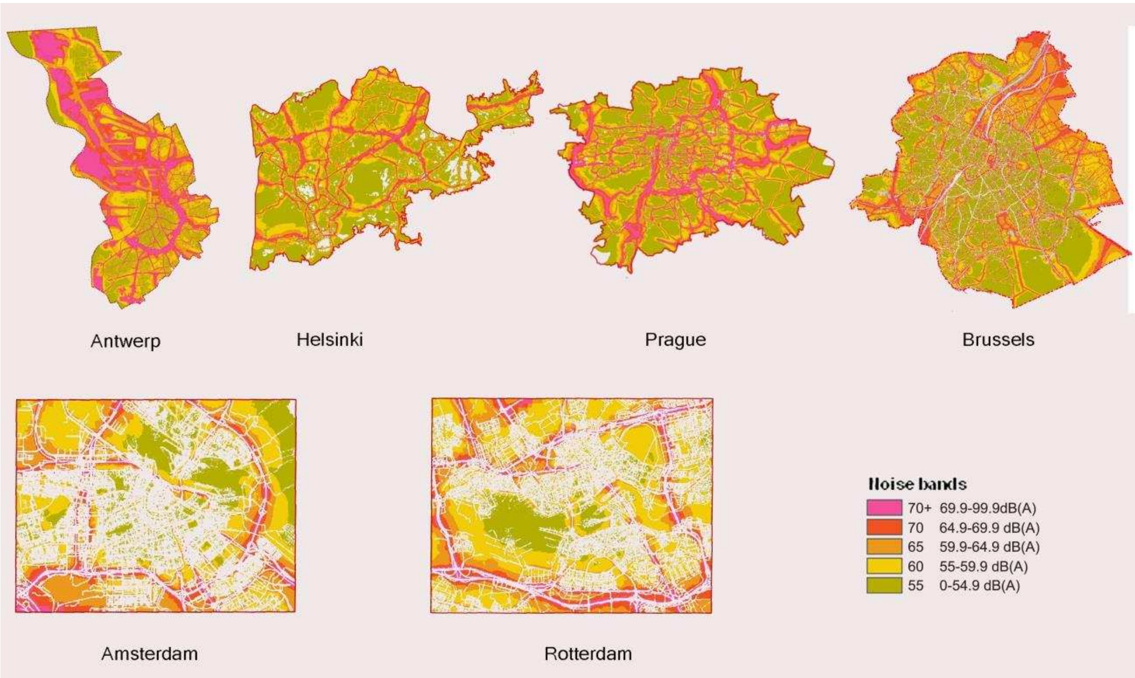

Fig. 3. Representation of the noise maps for the six cities using a common noise band scale.

In this level seven different noise indices - as presented in Table 4 - were formulated and tested in order to check which one can better describe the extent of noise pollution in the cities. Overall, three main approaches were adopted. In the first one the main idea was to compare the number of pixels in the marginal bands of 55 dB(A) and over 70 dB(A) in each city. This was sorted out with different combinations as described in Δnoise 1-3. Another group of indicators (Δnoise 4, Δnoise 6) involved also the intermediate noise bands between 60 and 70 dB(A). Finally, the last index includes all the noise bands in a weighted sum. This index attributes inverse weights from 1 to 5 by enhancing the lower noise bands and diminishing the importance of the higher ones. The identification of the most suitable noise index is based on the highest correlation between noise and green space indices.

Apart from the above indicators, other parameters were also tested for possible correlations with green space variables and proved unsuccessful. More specifically, these include the Building and Road Coverage, as well as five classes of the road network hierarchy (Motorway, Residential, Primary, Secondary and Tertiary) defined as ratios of the total road length.

Table 4
Noise and green variables tested.

Variables	Definition / Notes	Formula
Ratio per noise band		
p55	% of noise pixels - 0 - 54.9 dB(A)	p55 = 55(i) / sum (noise pixels)
p60	% of noise pixels - 55 - 59.9 dB(A)	p60 = 60(i) / sum (noise pixels)
p65	% of noise pixels - 60 - 64.9 dB(A)	p65 = 65(i) / sum (noise pixels)
p70	% of noise pixels - 65 - 69.9 dB(A)	p70 = 70(i) / sum (noise pixels)
p70p	% of noise pixels - 70 - 99 dB(A)	p70p = 70p(i) / sum (noise pixels)
p(x)(i), x=55,..70p	number of pixels per noise band	
Noise indices		
Δnoise 1	Index proportional to noise (↑↑)	Δnoise1 = p70p/p55
Δnoise 2	Index proportional to noise (↑↑)	Δnoise2 = p70p / p55 + 70p
Δnoise 3	Index inversely proportional to noise (↑↓)	Δnoise3 = sum (p55-p70) / p70p
Δnoise 4	Index inversely proportional to noise (↑↓)	Δnoise4 = p55 / [average (p60 - p70p]
Δnoise 5	Index proportional to noise (↑↑)	Δnoise5 = p70p / [(average (p55-p70p)]
Δnoise 6	Index inversely proportional to noise (↑↓)	Δnoise6 = [(p55 / p70p) * (1 / sum (p60-p70)]
Δnoise 7	Index inversely proportional to noise (↑↓)	Δnoise7 = [5*p55+4*p60+3*p65+2*p70+p70p]
Green space indices		
Green Space Ratio (Δgsr)	% total green spaces	Δgsr = Green space surface / Sum area
Extent of porosity (Δporous)	% porous to non-porous surfaces	Δporous = Δgsr / (BCOV + RCOV)
Forest ratio (Δtrees)	% green space classified as "trees"	Δtrees = Area of trees / Sum area
Free field ratio (Δfree field)	% green space classified as "free field"	Δfree field = Area of free field / Sum Area
BCOV	Buildings ratio	BCOV = Area of buildings / Sum area
RCOV	Road Coverage ratio	RCOV = Road area / Sum area

2.2.3 Green space data and indicators

There are various classification typologies for green spaces, which vary between eight and nine categories depending on the classification criteria (Bell et al., 2007; Panduro and Veie, 2013).

In this research, a first set of indicators was established referring to the green space coverage in the cities; firstly as a ratio compared to the whole area (Δgsr) and secondly as a percentage between porous and rigid areas (Δporous) as presented in Table 4. Green space data were extracted by Mapzen (Mapzen, 2016), which uses the latest Openstreetmap dataset under an open license.

A second set of indicators was formulated from the sound propagation perspective, where noise attenuation is higher with the presence of trees and lower with grass or any other low vegetation (ISO 9613-B). Subsequently, the indicators established were named as “Δtrees” and “Δfree field”. The first one refers to areas with a predominant presence of trees such as forests, nature reserves and orchards, while the second one involves lower vegetation with grass, scrubs, allotments or parks. Finally, Openstreetmap was selected as a more favourable dataset compared to Urban Atlas, since in the second case data were not available for all cities.

2.3 Kernel level

In the last level of analysis a more focused approach was followed using the previous six cities so as to test the same correlations between noise and green in a larger scale. Specifically for this analysis a Geographically Weighted Regression (GWR) approach was applied, which can better describe the geographical variations between the variables instead of assuming that a single linear model can be fitted to the entire study area (Bristol University, 2009) The parameters used in the GWR tool in ArcGIS (ESRI, 2016a) include a fixed kernel type combined with the AICc bandwidth method, which can identify the optimal adaptive number of neighbours for each case study area. The produced output refers to a multipart area composed of various 500x500 meter-pixel blocks.

In order to bring the noise and green space data in an applicable format for the GWR, some steps had to be followed in advance. First of all, by using the Block Statistics tool in ArcGIS (ESRI, 2016b), green space data were aggregated using the rectangular neighbourhood option. The aggregation field distinguishes forest areas from free field areas (grass) by applying a weight of “2” in the first case and a weight of “1” in the second case. For the noise data the same tool was used calculating the average values of the cells. The final output files ranged between 1 to 5,000 for the green areas and 55 to 80 dB(A) for noise levels. However, the final resolution in both datasets was adjusted to 500x500m as depicted in Fig.4 so as to keep a balance between precision and calculation time.

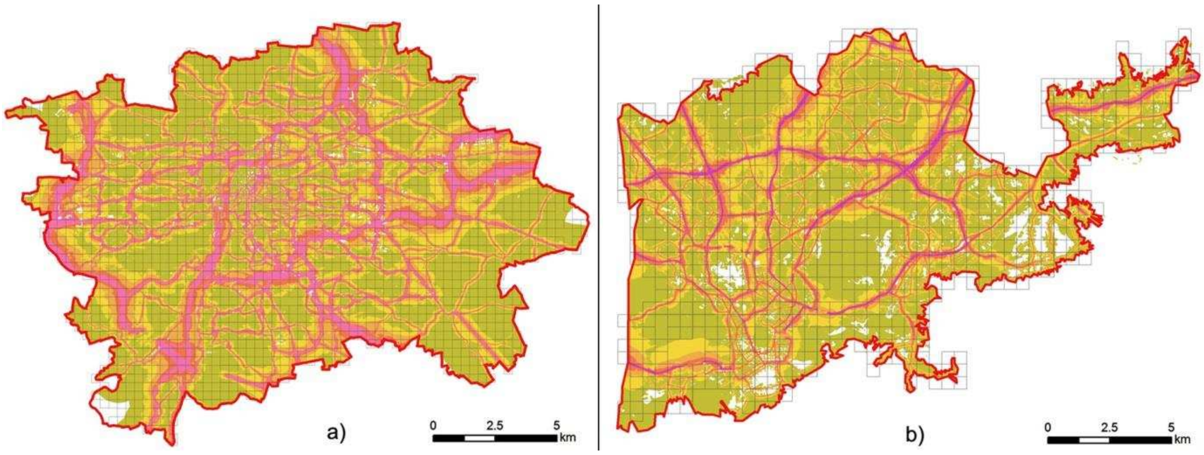

Fig 4. Example of the applied kernel (500x500m) in Prague (a) and Helsinki (b).

In the final step, a cluster analysis was applied in order to identify the character of each cluster in terms of land cover characteristics. The Grouping Analysis tool (ESRI, 2016c) was used for this purpose with no spatial constraints, which allows features to be grouped only based on their spatial proximity. Practically this process works in the same way as the k-means partitioning method. At last, the produced clusters were intersected with CORINE land cover data (European Environment Agency, 2006) of the finest resolution (100m x 100m) in order to get a more precise idea concerning the spatial distribution of the clusters.

3. Results

3.1 Effect of green spaces on noise at the agglomeration level.

The question investigated at this level is whether there is an effect of different green space categories such as forests, urban green and agricultural areas on noise. For this reason a first cluster analysis was performed in order to divide the agglomerations in groups of "high" and "low" green space areas per person. The particular cluster analysis can make the identification of correlations between noise and green easier, since direct linear relationships between the two variables were not found.

For the identification of possible clusters within the agglomerations a hierarchical analysis with the three green space categories - where population is also involved - was applied using the Ward's method in SPSS. The analysis of coefficients and the "elbow rule" showed that the optimal number of clusters is two. According to this result, the 25 agglomerations were classified in two groups of high and low green, as depicted in Fig.5a.

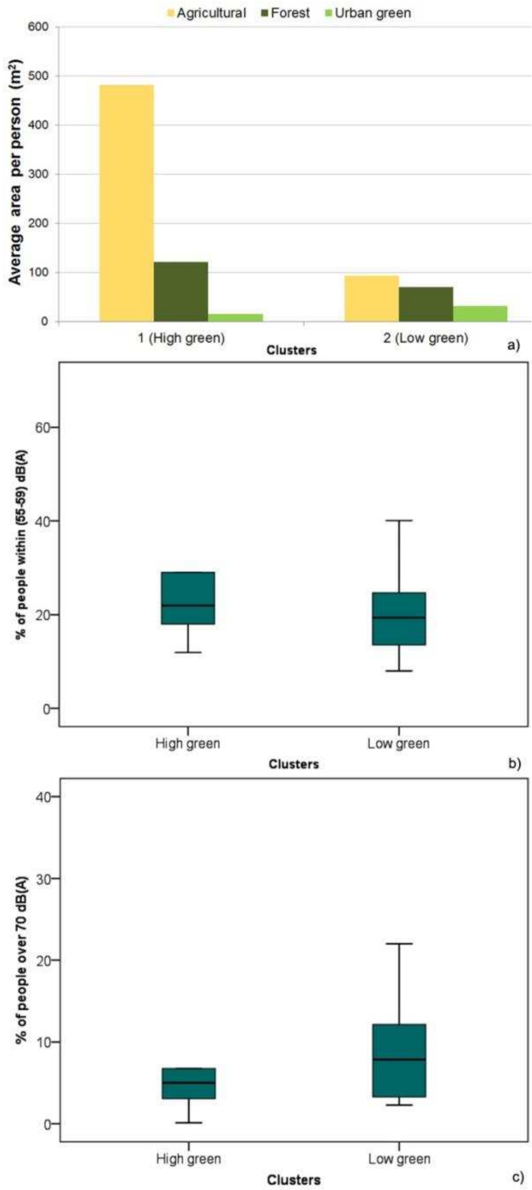

Fig. 5. Analysis in the 25 agglomerations**:** (a) Levels of green space per person in the two clusters, (b) percentage of people within the 55-59 dB(A) noise band, (c) percentage of people over 70 dB(A) according to the hierarchical analysis.

The first cluster contains six agglomerations (Alicante, Bruges, Burgas, Innsbruck, Ruse, Vitoria-Gazteiz) with high percentage of agricultural and forest areas, while the urban green is low. On the contrary, the second cluster with 19 agglomerations is more balanced among the three categories with a slightly higher percentage of urban green, but lower average green space area per person in the other two categories compared to the first cluster.

The first independent samples T-test was applied solely for the green space categories. It was found that there was a significant difference in the mean values of agricultural ($t(23)=6.7$, $p=.002$) and urban green ($t(23)=-4.6$, $p=.002$) between the two groups of cities. On the contrary, there was no difference in the mean values of the forest areas ($t(23)=-2.5$, $p=.80$). The second T-test was then applied in order to test the hypothesis that the percentage of people exposed to the lowest noise band (55-59) and the cluster with the higher percentage of green (cluster 1) are positively correlated. The same process was followed in order to check whether there is a negative correlation between the percentage of people exposed to the highest noise band (>70) and cluster 1.

Results from both tests proved that the variances between the two clusters were different from each other ($t(23)_{55\text{-}59}=1.21$, $p=.23$ and $t(23)>70=-1$, $p=.32$.), however these differences were not statistically significant as it can also be seen in the box-plots of Figs.5b,5c. In spite of this fact and taking into account the scale of analysis, there is a tendency, showing that more people are inclined to live in cluster 1 (Fig.5b). Similarly in Fig. 5c it can be seen that the majority of people living in areas of more than 70 dB(A) belongs within cluster 2, where all green space indices are lower.

In an attempt to identify similarities in the characteristics of the agglomerations within each cluster it was shown that cities in the first group have a population density lower than the average. From a land use perspective, according to the Urban Atlas classes, these agglomerations are mostly covered by “discontinuous low density urban fabric” mixed with industrial activities around the core urban area. Moreover, these places are characterised by a clear segregation between urban and green classes, with a low percentage of mixture.

On the contrary, the second cluster involves agglomerations with 43% higher population density on average than cluster 1. A higher coverage in the “continuous” and “discontinuous” dense urban fabric was also observed, which is expected due to the population density increase. Finally, there is a higher percentage of mixture between green and urban classes in contrast with the segregated landscape of cluster 1.

3.2. Effect of green space indicators on noise in the urban level

3.2.1 Trends between noise and green

Initially, a graphic representation of the variations between noise and green (Δtrees+Δfield) was produced so as to identify possible common trends among the six cities. According to Fig.6 three different trends in terms of noise and green can be recognised.

The first one refers to cities like Helsinki and Prague where there is a parallel decreasing tendency both in the number of noise pixels and green for each noise band. Moreover, both cities represent cases with a very high proportion of quiet areas, which belong in the 55 dB(A) band and the highest proportion of green in the same frequency. A variation of this trend can also be identified in the cities of Amsterdam and Rotterdam, where the decreasing tendency in noise and green starts from 60 dB(A) instead of 55 dB(A).

The second trend refers to cities like Brussels, where noise has a more normal distribution among noise bands compared to the first trend. Moreover, green and noise follow opposite tendencies in the middle noise bands demonstrating that the relationship between these two indices is not always proportional.

Finally, the last trend refers exclusively to the city of Antwerp, since it presents a pattern, which is opposed to the expected one as observed in the first trend. Cities in this category have relatively high percentage of green spaces and high noise levels with small variations in all bands. It is also interesting that in Antwerp noise and green present an increase also in the highest frequency. One of the possible reasons for this profile is the fact that Antwerp is also a Trans - European Transport Networks corridor with many highways and constant traffic.

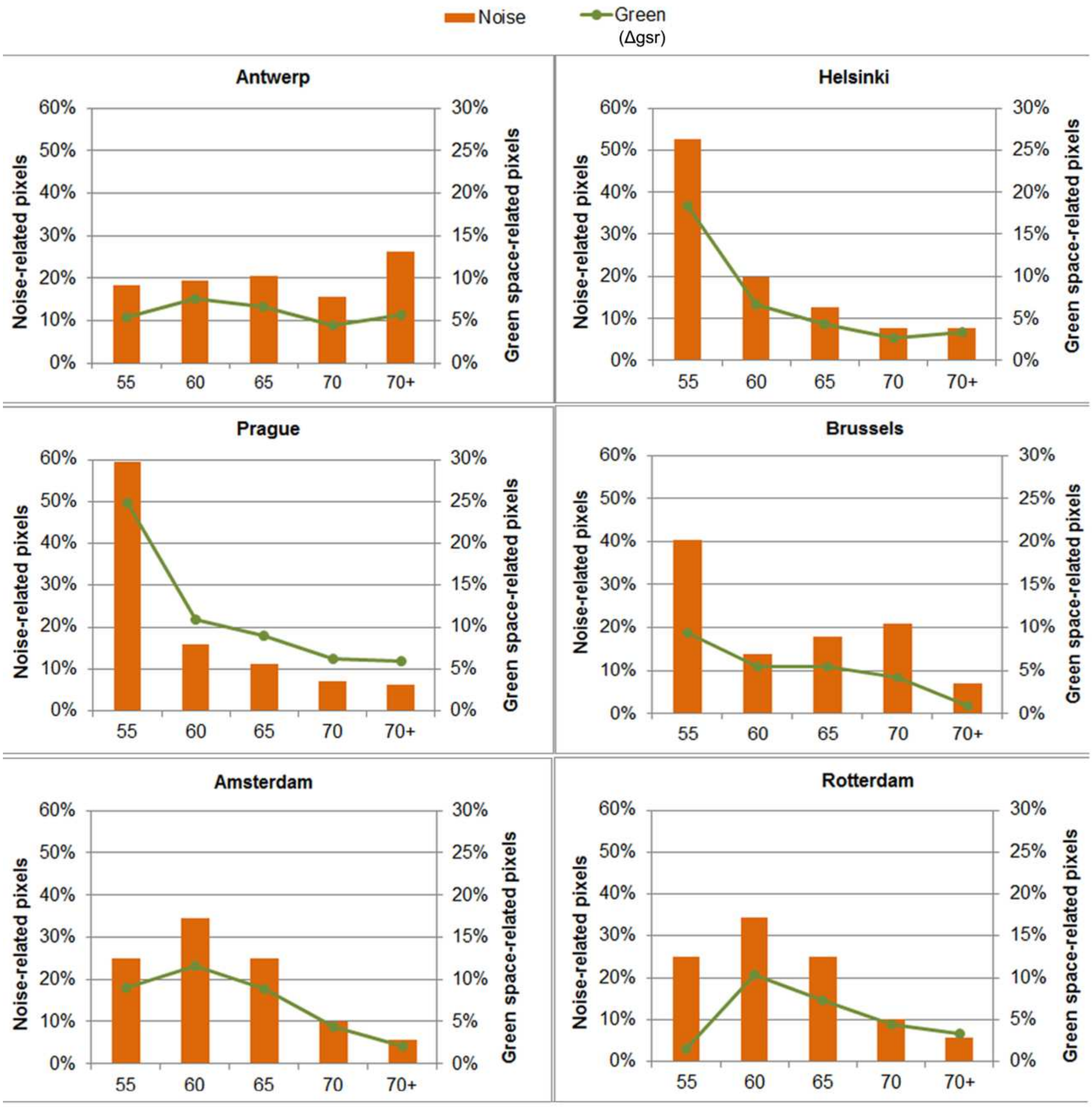

Fig. 6. Comparison of the percentage related to noise pixels and pixels related to Green Space Coverage (Δgsr) for the six cities.

3.2.2 Correlations between noise and green space indicators

The effect of green space indicators on noise indices was investigated in the urban level by using all the related variables (Table 4). A Pearson product-moment correlation coefficient was computed to assess the relationship between the seven noise indices and the four green space dependent variables. Results proved that there was a positive correlation for two of them. In particular Δnoise4 was positively correlated with Δporous ($r=.76$, $n=6$, $p=.045$) and Δgsr ($r=.82$, $n=6$, $p=.023$). Similarly Δnoise6 had a positive correlation with Δporous ($r=.79$, $n=6$, $p=.035$) and Δgsr ($r=.85$, $n=6$, $p=.016$). The scatterplot presented in Fig.7 summarizes these results. As Fig.7a shows lower noise levels - expressed with high values of Δnoise4 ($R^2=.72$) and Δnoise6 ($R^2=.80$) - can be achieved with higher levels of porous surfaces. Similar results can be achieved with an increase in the green space coverage (Δgsr) as shown in Fig.7b reaching a high coefficient of determination ($R^2 >.90$).

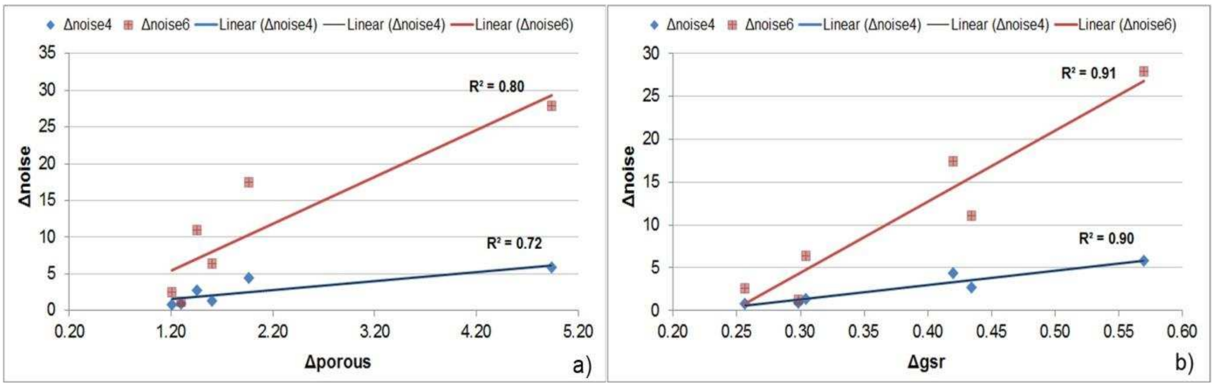

Fig. 7. Coefficient of determination (R^2) between Δnoise4, Δnoise6 and (a) Δporous, (b) Δgsr

A simple linear regression model was then calculated to predict noise levels (Δnoise6) based on Δporous and Δgsr. The formulated regression equation provided statistically significant results ($F(2,4)=25.1$, $p<.05$) with an R^2 of .92. The variable of Δporous had the highest contribution in the model ($R^2=.62$) and Δgsr contributes with an additional value of $R^2=.30$. Practically this means that the balance of porous surfaces in a city can possibly contribute to the reduction of traffic noise through proper land use planning.

3.2.3 Ranking of cities based on the selected noise index

The selection of Δnoise6 as the most suitable noise index at the urban level provides the opportunity to rank the case study cities from the "quietest" to the "noisiest". The ranking process among the cities as presented in Fig.8 showed that the less noise-polluted city at this level is Prague, with Helsinki, Brussels, Amsterdam, Rotterdam and Antwerp to follow. The results reveal that the sequence of cities according to the noise index is not always the same with the order of cities based on the porosity index or the green space coverage. Practically this means that quieter cities can potentially be greener, however this does not always work vice versa. For example, Amsterdam appears quieter than Brussels; however Brussels has a higher ratio of green space coverage (Fig.8).

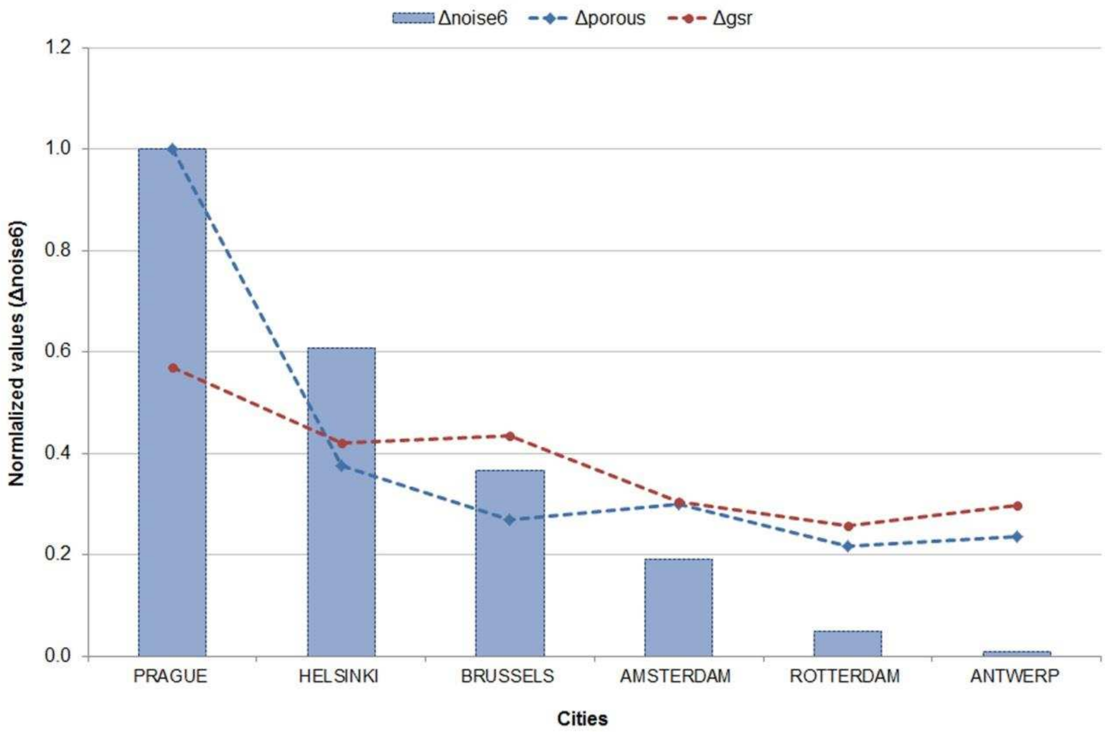

Fig. 8. Ranking of cities from the quietest to the noisiest and interaction with Δporous and Δgsr.

3.3 Effect of green space indicators on noise in the kernel level

At this level correlations between green and noise were tested for each city via a GWR approach by applying a moving search window in kernels of 500x500m. The sample of 14,932 observations (kernels) was big enough to facilitate this process. Then results were grouped into clusters in order to identify patterns between the green and noise variables. In the final stage, the groups were intersected with land cover data for a more comprehensive identification of the cluster characteristics.

At first, the corresponding results of the GWR presented in Fig. 9 gave significant correlations between noise and green with an R^2 range between .60 and .79. Such high correlations indicate that the relationship between the two variables varies locally and is more meaningful when analysed using a moving window approach with a fixed kernel. Prior attempts to interpret the same relationships using an Ordinary Least Squares (OLS) linear regression model provided insignificant results. Finally, as regards the cities, the highest correlation was calculated for Rotterdam (R^2=.79), while the lowest for Brussels (R^2=.60). Areas that present no results within the borders of each city represent kernels with no intersection between noise and green space data.

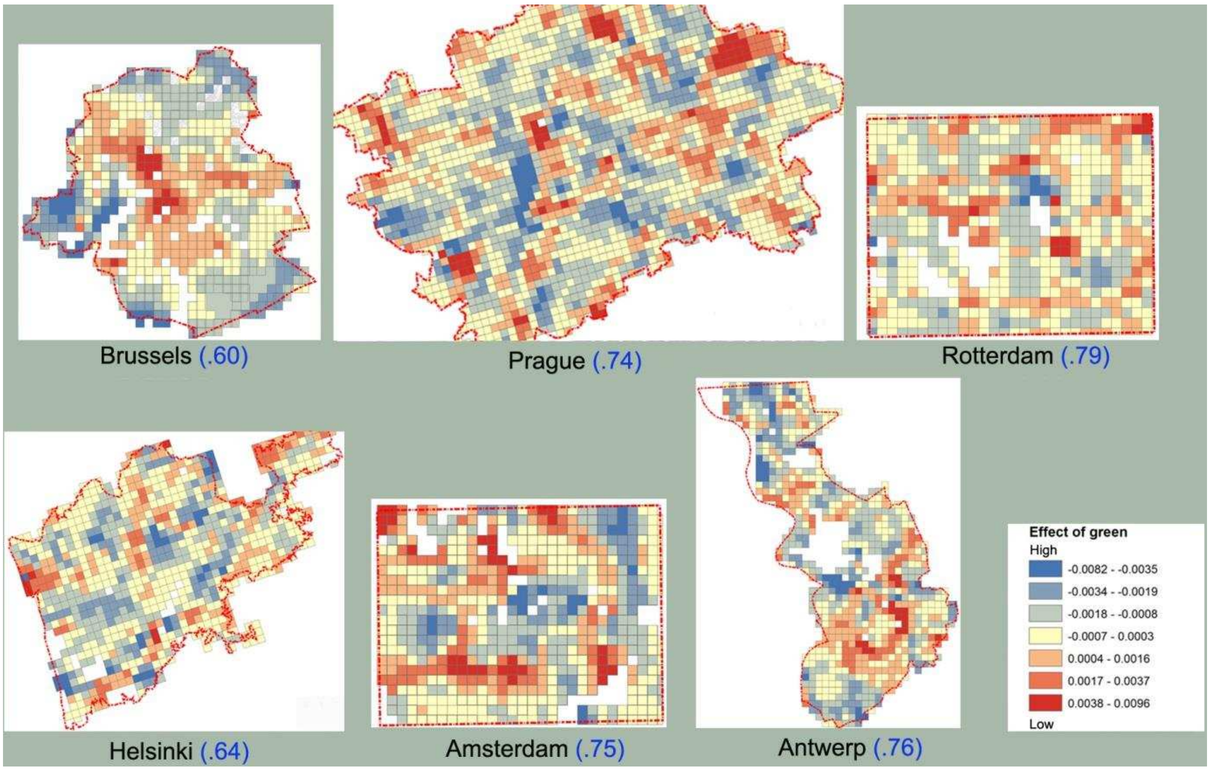

Fig. 9. The effect of green on noise according to the results of the GWR model and the associated coefficient of determination (R^2) for each city.

3.3.1 Ranking of cities

In order to test the consistency of the noise index (Δnoise6), which was selected for the analysis on the urban level, a similar approach was followed also for the kernel level. The index was recalculated for each area of 500x 500m and the final results were averaged for the entire cities. Results shown in Fig.10 present similarities and differences compared to the corresponding ones for the urban level (Fig.8). Specifically, three cities, namely Brussels, Rotterdam and Antwerp retained their ranking positions (3rd, 5th, 6th). On the contrary Prague was moved from the first position to the fourth, while small changes were evident for Helsinki, which was moved from the second to the first position. Finally, Amsterdam was ranked second instead of the fourth position in the urban level. Overall, it seems that the transition from one scale to the other had an impact on the noise assessment of the cities, although robust results in half of the case studies prove that the index has the potential to be consistent. Other parameters that were expected to have an effect on the final ranking comparison include the transformation of noise levels from discrete to continuous values and the selected size of the kernel (500x500). In all cases, these results can only provide a general initial insight for each city, which can further be elaborated during the planning process.

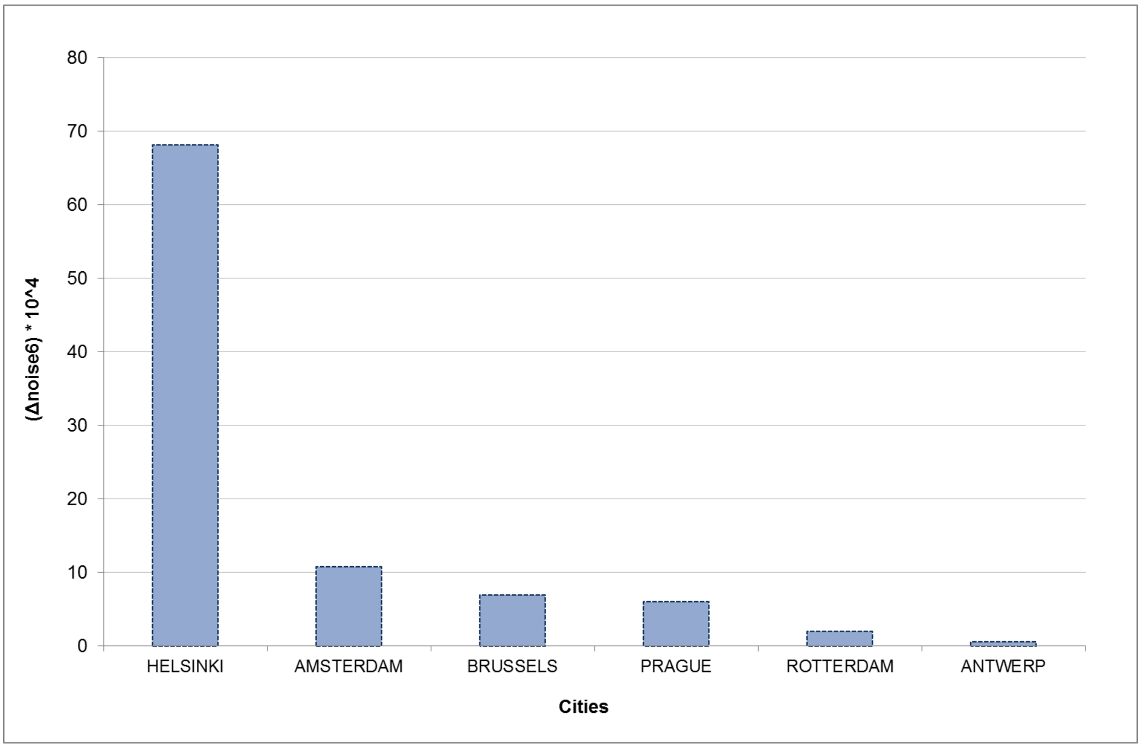

Fig. 10. Ranking of the cities from the quietest to the noisiest according to Δnoise6 calculated in the kernel level.

3.3.2 Cluster analysis in the kernel level

A cluster analysis was applied after the GWR results were obtained. This process can lead to a better understanding of the kernel areas according to the correlations between noise and green space indices. The optimal number of groups as presented in Fig.11a was equal to 3 according to the results from the total "within sum of squares" plot with the number of clusters. The graph in Fig 11b describes the balance of the two variables among each cluster. What can be concluded is that cluster 1 is typical of high green space coverage and low noise levels, while opposite characteristics are present for cluster 3. Lastly, cluster 2 presents a balanced amount of green and noise in lower proportions compared to the other two clusters.

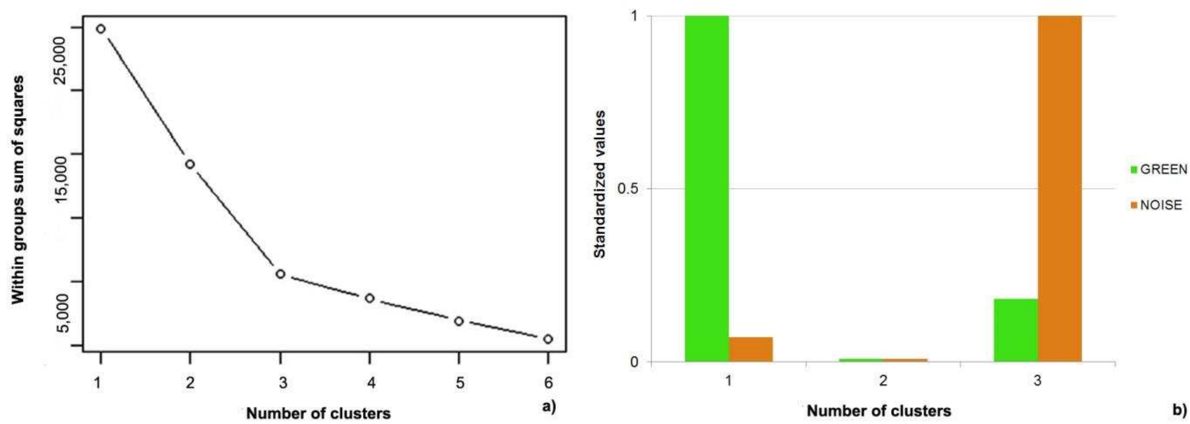

Fig. 11. (a) Number of clusters and variance explained (within groups sum of squares). The optimal number of clusters is determined according to the "elbow rule". (b) Cluster variations based on the balance between green and noise using standardised values.

The grouping analysis as shown in Fig.12 presents the spatial distribution of the three clusters in the case study cities. Areas representing "group 1" are typical of high green space coverage and low noise levels. Such areas are more representative in Prague (46%), Brussels (17%), Antwerp (16%) and Helsinki (15%), with fewer samples in the other cities. Areas of "group 2" represent kernels with low green space coverage and also low noise levels. This kind of places can be found in the majority of the territory in Helsinki (68%), Amsterdam (60%), Rotterdam (59%) and Brussels (58%). Finally, areas of "group 3" with high noise levels and low green space coverage were evident in all cities, however higher proportions were identified in Antwerp (51%), Rotterdam (35%), Amsterdam (31%) and Prague (30%).

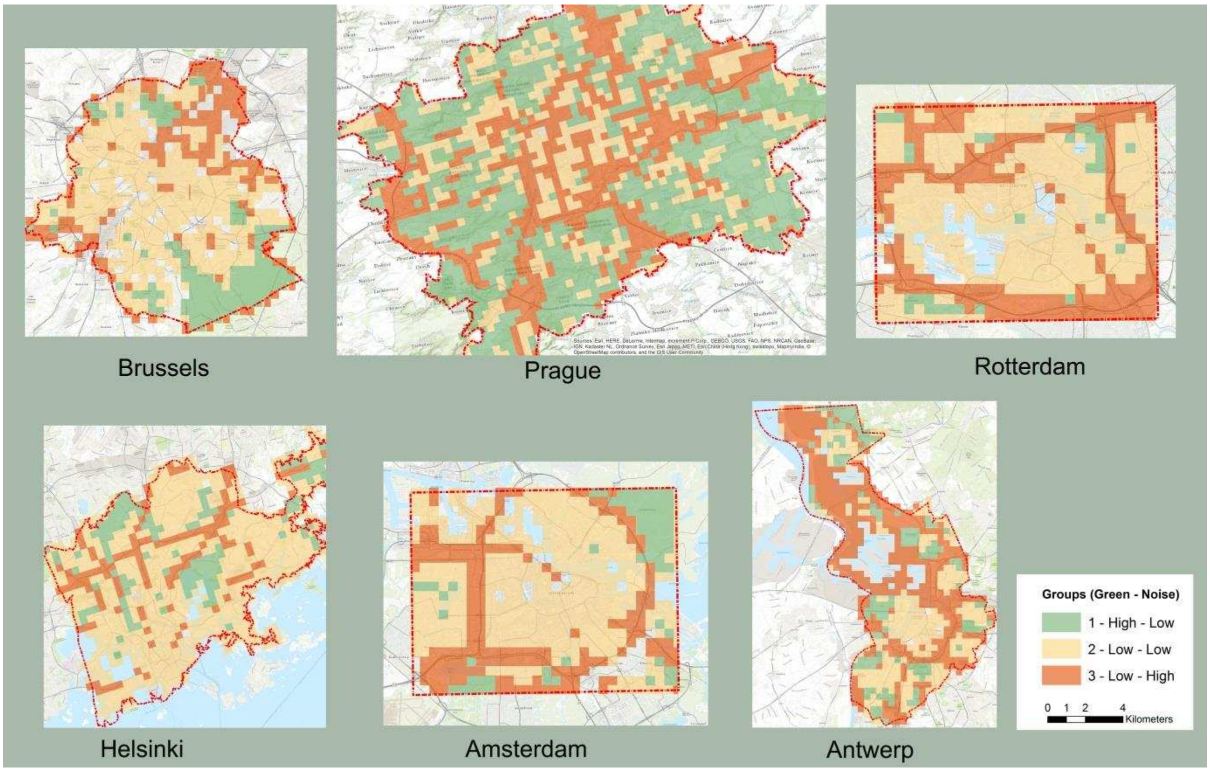

Fig. 12. Cluster analysis based on the k-means algorithm performed with the Grouping Analysis tool in ArcGIS. *Basemap Source: ESRI.*

More comprehensive conclusions can be drawn when combining the results of the cluster analysis with CORINE land cover data. The analysis as presented in Fig.13 revealed that over 30% of the agricultural and forest areas belong to cluster 1 as well as a small amount of the total urban areas (5%). Very low percentages were present in this group as regards industry, infrastructure, the rest of the vegetation and the water bodies.

Cluster 2, which has low levels of noise and green was found to include the highest percentage of total urban areas (21%) and very low proportions in all the other classes. The relationship between noise and green was not so evident in this group or at least results were poorly correlated even with a GWR approach. The highest amount of green spaces in this group was found in the forest class (14%).

Lastly, cluster 3 has the highest percentage in industry and infrastructure and also the lowest in forest areas. Urban areas constitute the class with the highest proportion in this group (10%) as in the other two clusters and agricultural areas depicted a higher percentage than cluster 2.

In general, cluster 3 appeared to have a reduced amount of green spaces compared to cluster 1. In particular, there was a reduction of 17% in forest and agricultural areas and 1% in the rest of the vegetation. Overall it was shown that at least in the marginal clusters (1,3) noise and green had an inversely proportional relationship.

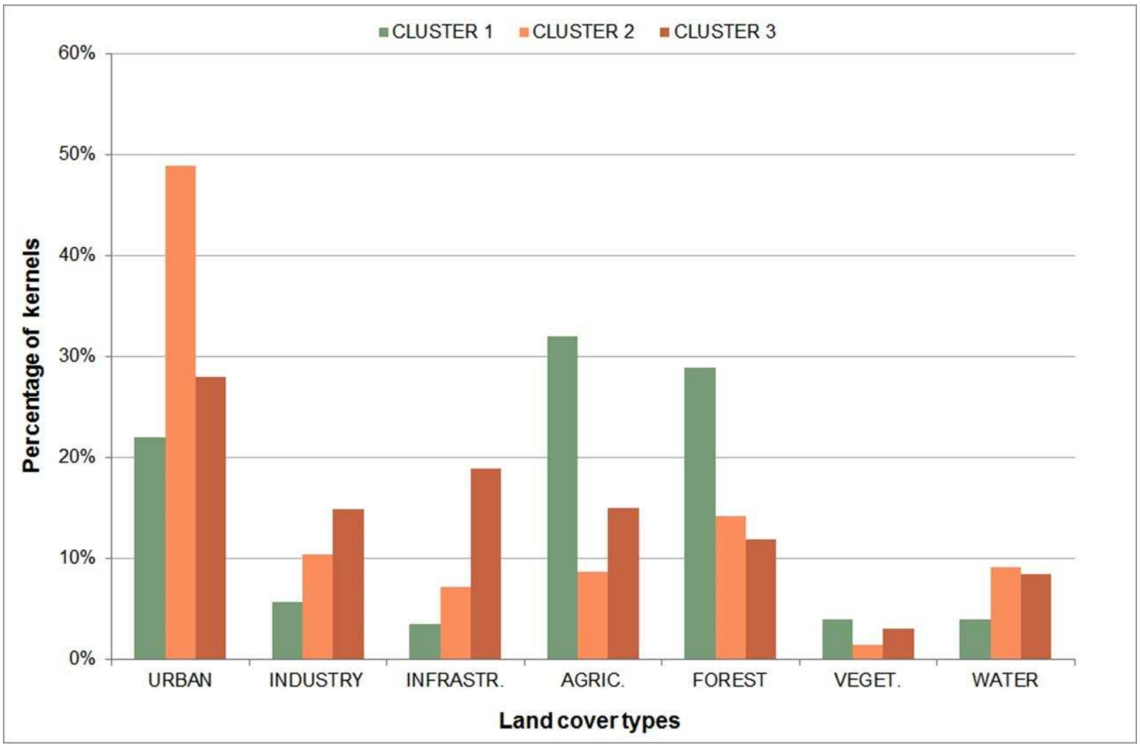

Fig. 13. CORINE land cover classes in the six cities distributed over the three clusters.

4. Conclusions

The purpose of this study was to investigate whether greener cities around Europe can also be quieter and less noise polluted. For this reason an analysis was conducted investigating possible correlations between green space-related indicators and traffic noise indices. The analysis was applied in three levels (agglomeration, urban, kernel) from a broader to a smaller scale. In the first level, 25 European agglomerations were selected, while six of them were further investigated on the urban and kernel level using noise data from online noise maps. In the kernel level, each one of the six cases previously mentioned was divided in grid areas (kernels) of 500x500m and a GWR analysis was conducted. Apart from the identified correlations, the kernels were further grouped in clusters and associated with land cover characteristics. Conclusions can be summarized as follows:

In the agglomeration level cities were divided in two clusters based on three green space categories and particularly the green area per person. The two groups of cities were found to be significantly different in agriculture and urban green ratio, with cluster 1 to present the highest proportions. However, there was not a direct correlation between green space indices and the population exposed in low (55-59 dB(A)) or high (over 70 dB(A)) noise bands. As a result, the hypothesis that the percentage of people, exposed in the 55-59 noise band, would be higher in the cluster with the higher green space index was not confirmed. The same happened with the hypothesis that the percentage of people exposed in more than 70 dB(A) would be higher in the cluster with the lower green space index. However, in both cases there were tendencies towards the validation of both hypotheses, since the variances between the two clusters were different from each other in the T-tests.

Concerning the land use attributes in the two clusters, it was found that cluster 1 was related to urban and industrial areas with low population density and high segregation between the green and urban classes. On the contrary cluster 2 was associated with high urban land cover and high population density, but lower segregation between green and urban areas.

In the urban level it was proved that quieter cities can potentially be greener, however this does not always work vice versa. On the top of that the analysis showed that lower noise levels can possibly be achieved in cities with a higher extent of porosity and green space coverage. Between the two variables, the extent of porosity was proved to have a higher contribution (R^2=.62) in the prediction of noise levels than the extent of green space coverage (R^2=.30). As regards the detected trends, three different kinds were found. The first one refers to cities, which present a parallel decreasing tendency both in noise levels and green starting from the lower and moving to the higher noise bands. The second trend refers to cities where noise had a more normal distribution among noise bands compared to the first trend. The last trend involves cities, which have a relatively high percentage of green spaces and also high noise levels with small variations in all noise bands.

In the kernel level, significant correlations were identified with the GWR approach and the coefficient of determination (R^2) to range between 60% and 79%. The clusters, which were formed by the data of all cities, showed that it was possible to classify kernels in three main groups. The first group was typical of high green space coverage and low noise levels. The second one presented a balance between noise and green, while the third one was typical of high noise levels and low green space coverage. While ranking the cities based on the same noise index (Δnoise6) recalculated for the kernel level, three of them namely Brussels, Rotterdam and Antwerp retained their ranking positions and the rest mainly presented small variations.

The cluster analysis at this level gave a number of three optimal clusters with the first one to present low noise levels and high green space ratio. The second one was more balanced between the two attributes, while the third one was exactly opposite to the first.

A further comparison of the three groups with the land cover data showed that noise levels were minimized in the group that had the highest percentage of forest and agricultural areas in combination with the minimum coverage of infrastructure, such as road or rail network, ports and airports. This cluster accounted for 23% of the total area in the six cities. On the contrary, the third cluster with the highest noise levels was combined with the maximum coverage of infrastructure and industrial land encompassing an area of 34%. Finally, the second cluster - with a total coverage of 43% - was typical of an urban environment with the highest proportion of urban land cover and low fluctuations in the other classes including industry, infrastructure and greenery.

Overall, the transition from one level to the other showed that the relationship between noise and green can vary. However, some core relationships especially in the urban and kernel level remained unchanged. In particular, the negative correlations in the urban level suggest that planners should emphasize more on the ratio between green space and built-up surfaces, since it seems to be more meaningful as an indicator compared to the green space coverage itself. The Modifiable Area Unit Problem (MAUP), while moving from the urban to the kernel level was minimised thanks to the small kernel size (500x500m) and the application of a moving window with a fixed kernel in the GWR. An Ordinary Least Square (OLS) regression was also applied, however the correlations were really poor proving that the relationship between noise and green cannot be represented by a single global model at that level.

A further research, in particular on the clusters' urban part in particular can reveal more in depth correlations between noise and green space features for the core parts of the cities. Specifically, the integration of noise mapping data in land use regression models can be more effective for noise pollution prediction during the urban and sub-urban areas early planning stage.

Acknowledgments

This research received funding from the People Programme (Marie Curie Actions) of the European Union's Seventh Framework Programme FP7/2007-2013 under REA grant agreement n° 290110, SONORUS "Urban Sound Planner". The authors are also thankful to Ms Nuria Blames and the GIS department of EIONET and to the City Councils of Helsinki and Prague for the noise and land use data allowance.

References

Aguilera, I., Foraster, M., Basagaña, X., Corradi, E., Deltell, A., Morelli, X., Phuleria, H.C., Ragettli, M.S., Rivera, M., Thomasson, A., Slama, R., Künzli, N., 2015. Application of land use regression modelling to assess the spatial distribution of road traffic noise in three European cities. J. Exposure. Sci. Environ. Epidemiol. 25, 97-105. doi:10.1038/jes.2014.61

Attenborough, K., 2002. Sound propagation close to the ground. Annu. Rev. Fluid Mech. 34, 51-82. doi:10.1146/annurev.fluid.34.081701.143541.

Aylor, 1972. Noise reduction by vegetation and ground. J. Acoust. Soc. Am. 51, 197-205.

Bell, S., Montarzino, A., Travlou, P., 2007. Mapping research priorities for green and public urban space in the UK. Urban For. Urban Green. 6, 103-115. doi:10.1016/j.ufug.2007.03.005.

Bolton, T., Hildreth, P., 2013. Mid-sized cities: Their Role in England's Economy. Centre for Cities, London.

Brambilla, G., Gallo, V., 2016. QUIETE: a scheme for a new index of the environmental quality of green areas. Noise Mapp. 3, 49-58. doi:10.1515/noise-2016-0004.

Brambilla, G., Gallo, V., Asdrubali, F., D'Alessandro, F., 2013. The perceived quality of soundscape in three urban parks in Rome. J. Acoust. Soc. Am. 134, 832-9. doi:10.1121/1.4807811.

Brambilla, G., Maffei, L., 2006. Responses to noise in urban parks and in rural quiet areas. Acta Acust. united Ac. 92, 881-886.

Bristol University, 2009. Introduction to Geographically Weighted Regression. http://www.bristol.ac.uk/media-library/sites/cmpo/migrated/documents/gwr.pdf (accessed 09.09.16).

Cohen, P., Potchter, O., Schnell, I., 2014. A methodological approach to the environmental quantitative assessment of urban parks. Appl. Geogr. 48, 87-101. doi:10.1016/j.apgeog.2014.01.006.

Department of Environemt, Food and Rural Affairs (DEFRA), 2007. Noise Mapping England: Maps and Charts. http://services.defra.gov.uk/wps/portal/noise (accessed 08.06.15).

De la Barrera, F., Reyes-Paecke, S., Banzhaf, E., 2016. Indicators for green spaces in contrasting urban settings. Ecol. Indic. 62, 212-219. doi:10.1016/j.ecolind.2015.10.027.

ESRI, 2016a. Interpreting GWR results. http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-statistics-toolbox/interpreting-gwr-results.htm (accessed 08.08.16).

ESRI, 2016b. Block Statistics. http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/block-statistics.htm (accessed 08.08.16).

ESRI, 2016c. Grouping Analysis. URL http://pro.arcgis.com/en/pro-app/tool-reference/spatial-statistics/grouping-analysis.htm (accessed 08.08.16).

European Commission, 2014. European Green Capital Award 2015 - Urban environment good practice and benchmarking report.

Environmental Noise Directive (END) 2002/49 of the European Parliament and the Council of 25 June 2002 relating to the assessment and management of environmental noise, 2002. Official Journal of the European Communities L189, 12-25.

European Environment Agency, 2006. Corine Land Cover raster data. http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-raster-2 (accessed 29.03.16).

European Environment Agency, 2010. Urban Atlas. http://www.eea.europa.eu/data-and-maps/data/urban-atlas (accessed 02.04.16).

European Environment Information and Observation Network (EIONET), 2015. Noise database http://forum.eionet.europa.eu/etc-sia-consortium/library/noise_database/index_html (accessed 11.03.16).

Fuller, R.A., Gaston, K.J., 2009. The scaling of green space coverage in European cities. Biol. Lett. 5, 352-355. doi:10.1098/rsbl.2009.0010.

González-Oreja, J.A., Bonache-Regidor, C., De La Fuente-Díaz-Ordaz, A.A., 2010. Far from the noisy world ? Modelling the relationships between park size , tree cover and noise levels in urban green spaces of the city of Puebla , Mexico. Interciencia 35, 486-492.

Goudreau, S., Plante, C., Fournier, M., Brand, A., Roche, Y., Smargiassi, A., 2014. Estimation of spatial variations in urban noise levels with a land use regression model. Environ. Pollut. 3, 48-58. doi:10.5539/ep.v3n4p48.

Hao, Y., Kang, J., Krijnders, D., Wörtche, H., 2015a. On the relationship between traffic noise resistance and urban morphology in low-density residential areas. Acta Acust. united Ac. 101, 510-519. doi:10.3813/AAA.918848.

Hao, Y., Kang, J., Krijnders, J.D., 2015b. Integrated effects of urban morphology on birdsong loudness and visibility of green areas. Landsc. Urban Plan. 137, 149-162. doi:10.1016/j.landurbplan.2015.01.006.

Herzele, A. Van, Wiedemann, T., 2003. A monitoring tool for the provision of accessible and attractive urban green spaces. Landsc. Urban Plan. 63, 109-126. doi.org/10.1016/S0169-2046(02)00192-5.

Hillsdon, M., Panter, J., Foster, C., Jones, A., 2006. The relationship between access and quality of urban green space with population physical activity. Public Health 1127-1132. doi:10.1016/j.puhe.2006.10.007.

Horoshenkov, K. V, Khan, A., Benkreira, H., 2013. Acoustic properties of low growing plants. J. Acoust. Soc. Am. 133, 2554-65. doi:10.1121/1.4798671.

Huddart, L., 1990. The use of vegetation for traffic noise screening, Publication of: Transport and Road Research Laboratory. Crowthorne, Berkshire, England.

ISO 37120: Sustainable development of communities - Indicators for city services and quality of life, 2014. http://www.iso.org/iso/catalogue_detail?csnumber=62436 (accessed 12.03.16).

ISO 9613-B: Acoustics-Attenuation of sound during propagation outdoors - Part 2: General method of calculation, International Standard Organization, Geneva, Switzerland, 1996. http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=20649 (accessed 12.03.16).

Kabisch, N., Strohbach, M., Haase, D., Kronenberg, J., 2016. Urban green space availability in European cities. Ecol. Indic. 70, 586-596. doi:10.1016/j.ecolind.2016.02.029.

Lercher, P., Schulte-Fortkamp, B., 2015. Soundscape of European Cities and Landscapes - Harmonising., in: Final Conference of Soundscape-COST-TD0804-Project. Merano. doi:10.13140/2.1.3030.1127.

Mapzen, 2016. Open source map platform. https://mapzen.com/ (accessed 12.01.16).

Margaritis, E., Kang, J., 2016. Relationship between urban green spaces and other features of urban morphology with traffic noise distribution. Urban For. Urban Green. 15, 174-185. doi:10.1016/j.ufug.2015.12.009.

McGarical, K., Marks, B.J., 1994. FRAGSTATS: Spatial pattern analysis program for quantifying landscape structure. Oregon State University, Corvallis.

Mõisja, K., Uuemaa, E., Oja, T., 2016. Integrating small-scale landscape elements into land use / cover : The impact on landscape metrics ' values. Ecol. Indic. 67, 714-722. doi:10.1016/j.ecolind.2016.03.033.

Morar, T., Radoslav, R., Spiridon, L.C., Păcurar, L., 2014. Assessing pedestrian accessibility to green space using GIS. Transylvanian Rev. Adm. Sci. 42, 116-139.

Natural England, 2010. Nature Nearby, Accessible Natural Greenspace Guidance. http://publications.naturalengland.org.uk/publication/40004?category=47004 (accessed 05.10.15).

Oliveira, M. F., & Silva, L. T. (2010). How urban noise can be influenced by the urban form. Proceedings in *Advances in Biology, Bioengineering and Environment* 2010.Athens,Greece, pp.31-36.

Panduro, T.E., Veie, K.L., 2013. Classification and valuation of urban green spaces - A hedonic house price valuation. Landsc. Urban Plan. 120, 119-128. doi:10.1016/j.landurbplan.2013.08.009.

Pheasant, R.J., Horoshenkov, K. V., Watts, G.R., 2010. Tranquillity rating prediction tool (TRAPT). Acoust. Bull. 35, 18-24.

Ragettli, M.S., Goudreau, S., Plante, C., Fournier, M., Hatzopoulou, M., Perron, S., Smargiassi, A., 2016. Statistical modeling of the spatial variability of environmental noise levels in Montreal, Canada, using noise measurements and land use characteristics. J. Expo. Sci. Environ. Epidemiol. 1-9. doi:10.1038/jes.2015.82.

Hosanna.,2014. WP3: Trees, shrubs and bushes. http://www.greener-cities.eu/ (accessed 15.1.14).

Salomons, E.M., Berghauser Pont, M., 2012. Urban traffic noise and the relation to urban density, form, and traffic elasticity. Landsc. Urban Plan. 108, 2-16. doi:10.1016/j.landurbplan.2012.06.017.

Schwarz, N., 2010. Urban form revisited-Selecting indicators for characterising European cities. Landsc. Urban Plan. 96, 29-47. doi:10.1016/j.landurbplan.2010.01.007.

Silva, L.T., Oliveira, M., Silva, J.F., 2014. Urban form indicators as proxy on the noise exposure of buildings. Appl. Acoust. 76, 366-376. doi:10.1016/j.apacoust.2013.07.027.

Ståhle, A., 2010. More green space in a denser city: Critical relations between user experience and urban form. Urban Des. Int. 15, 47-67. doi:10.1057/udi.2009.27.

Tang, U.W., Wang, Z.S., 2007. Influences of urban forms on traffic-induced noise and air pollution: Results from a modelling system. Environ. Model. Softw. 22, 1750-1764. doi:10.1016/j.envsoft.2007.02.003.

The Economist, 2009. European Green City Index, Siemens AG. https://www.siemens.com/entry/cc/features/greencityindex_international/all/en/pdf/gci_report_summary.pdf (accessed 05.11.15).

United Nations, 2012. World Urbanization Prospects: The 2011 Revision http://www.un.org/en/development/desa/population/publications/pdf/urbanization/WUP2011_Report.pdf (accessed 05.02.16).

Valente-Pereira, L., 2014. Urban form definition in urban planning. Revolução eBook

Van Renterghem, T., Attenborough, K., Maennel, M., Defrance, J., Horoshenkov, K., Kang, J., Bashir, I., Taherzadeh, S., Altreuther, B., Khan, A., Smyrnova, Y., Yang, H.-S., 2014. Measured light vehicle noise reduction by hedges. Appl. Acoust. 78, 19-27. doi:10.1016/j.apacoust.2013.10.011.

Van Renterghem, T., Botteldooren, D., Verheyen, K., 2012. Road traffic noise shielding by vegetation belts of limited depth. J. Sound Vib. 331, 2404–2425. doi:10.1016/j.jsv.2012.01.006.

Verani, E., Pozoukidou, G., Sdoukopoulos, A., 2015. The effect of urban density, green spaces and mobility patterns in cities' environmental quality: An empirical study of the metropolitan area of Thessaloniki. Spatium 8-17. doi:10.2298/SPAT1533008V.

Votsi, N.E.P., Drakou, E.G., Mazaris, A.D., Kallimanis, A.S., Pantis, J.D., 2012. Distance-based assessment of open country quiet areas in Greece. Landsc. Urban Plan. 104, 279-288. doi:10.1016/j.landurbplan.2011.11.004.

Weber, M., 2012. The soundscape of nature areas : assessment and review of research approaches, in: Proceedings of the Acoustics 2012. Nantes, France, pp. 2139-2144.

Weber, N., Haase, D., Franck, U., 2014. Traffic-induced noise levels in residential urban structures using landscape metrics as indicators. Ecol. Indic. 45, 611-621. doi:10.1016/j.ecolind.2014.05.004.

World Health Organization (WHO), 2009. Night noise guidelines for Europe.

World Health Organization (WHO), 2010. Urban planning, environment and health.

Yang, H., Kang, J., Cheal, C., 2011. Sound dispersion and reverberation by a single tree, in: Internoise. pp. 1-10.

Zhao, J., Chen, S., Jiang, B., Ren, Y., Wang, H., Vause, J., Yu, H., 2013. Temporal trend of green space coverage in China and its relationship with urbanization over the last two decades. Sci. Total Environ. 442, 455-465. doi:10.1016/j.scitotenv.2012.10.014.